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EFFECT OF NORMAL PRESSURE ON THE CRITICAL COMPRESSIVE AND SHEAR STRESS OF CURVED SHEET

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ADVANCE RESTRICTED REPORT

EFFECT OF NORMAL PRESSURE ON THE CRITICAL COMPRESSIVE AND SHEAR STRESS OF CURVED SHEET

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SUMMARY

Results are presented of tests of two sets of 20 curved-sheet specimens to determine the effect of normal pressure on the critical compressive and shear stress of curved sheet. It was found that normal pressure raised the critical compressive and shear stress of curved sheet except when outward bulging occurred in compression, in which case the critical stress was lowered by normal pressure.

INTRODUCTION

In a pure shell-type wing structure, failure is generally associated with buckling of the upper surface due to combinations of compressive and shear loads. The net outward-acting pressure on the upper surface tends to delay buckling and to increase the critical buckling stress.

Preliminary tests have been made of curved-sheet specimens (references 1 and 2) to determine the effect of normal pressure on the critical compressive and shear stress of curved sheet. In these tests, increases in critical stress with increases in normal pressure were so decided that a more complete investigation seemed necessary. As a result, tests have been made of 40 curved-sheet specimens in which combinations of five different radii of curvature and four different rib spacings were used. One set of 20 specimens was tested to determine the effect of normal pressure on the critical compressive stress, and a similar set of 20 specimens was tested to determine the effect of normal pressure on the critical shear stress. It is the purpose of this report to present the results of these tests.

[redacted]

TEST SPECIMENS

The test specimens were constructed as shown in figure 1. Nominal dimensions for all test specimens are given in table I. The sheets and the spar channels that form the sides of the closed box were made of 24S-T aluminum alloy. The ribs were made of steel with the flanges welded to the webs. As shown in figure 1, the end bays were made shorter than the three center bays, hereafter referred to as the test section, in order to confine buckling to the test section.

The specimens were so sealed that the air pressure was confined to the test sections. Air fittings were provided in the channels at diagonally opposite corners of the test section; and holes drilled through the two center ribs ensured equal pressure in the three bays. The pressure was measured by means of a mercury manometer. Resistance-type wire strain-gage rosettes were attached in the center bay of the specimen to each side of one sheet as shown in figure 1. These gages were used to check for uniform loading and to detect the formation of buckles, which did not appear with a snap diaphragm action.

METHOD OF TESTING

Compression Tests

A specimen placed in the testing machine is shown in figure 2. The testing machine had an accuracy of $\pm\frac{1}{2}$ percent of load. The ends of the specimen were ground flat and parallel to ensure uniform distribution of load during the tests.

A small initial axial load was applied and readings of all the gages were taken. The axial load was then increased in steps until buckling occurred. After each load increment had been applied, readings of all the gages were taken. So long as no buckling occurred, the longitudinal gages indicated increasing compressive strain with load. When buckling began, the strain on the convex side of the buckle was reduced by the tensile stress incident to buckling; the reading of the gage on this side, consequently, did not continue to increase uniformly with load but reached a maximum and then started to decrease. The load corresponding to the maximum gage reading was considered the buckling load for all panels in which no snap buckling occurred.

A similar procedure was then used to test each specimen with internal air pressure. The air pressure was admitted after readings were taken at the initial load. The pressure was then held constant and the axial load was increased in steps until buckling occurred. The tests were continued at several different higher pressures with the highest permissible pressure being determined both by visual inspection of the amount of quilting and by approximate computations based on reference 3. The highest permissible pressure is defined as that pressure which can be admitted without exceeding the yield stress of the material. When the highest permissible pressure exceeded 6 psi, only pressures up to 6 psi were used.

Torsion Tests

The testing procedure for the torsion tests was similar to that used in the compression tests with the exception that there was no initial load on the specimen. Figure 3 illustrates the manner of loading a specimen in torsion and shows the locations of the dial gages used to measure the amount of rotation. The steel plate to which the specimen was fastened was connected to a weighing system that measured torque and vertical load with an accuracy of ±1 percent. In testing, the only load applied to the specimen was a pure torque.

RESULTS

The results of the tests are given in figures 4 to 8. Figures 4 and 5 show the effects of R/t and rib spacing on the critical stresses without normal pressure, where R is the radius of curvature of the sheet and t is the thickness of the sheet. The critical compressive stress was obtained by dividing the buckling load by the total cross-sectional area of the specimen.

The critical compressive stresses indicated by points with tails in figure 4 are stresses that correspond to the loads at which the strain-gage readings reversed direction. For the specimens with 6-inch rib spacing, the points with tails represent tests in which the sheets bulged outward in all bays. All other tailed points represent tests in which combinations of inward and outward buckling occurred gradually. Points without tails represent tests in which snap diaphragm buckling occurred.

The critical shear stress was obtained from the formula

$$\tau = \frac{T}{2At}$$

where

τ shear stress, psi

T buckling torque, inch-pounds

A area enclosed by median line of sheet and spars, square inches

t thickness of sheet, inches

The critical shear stresses indicated by the tailed points in figure 5 are stresses that correspond to the strain-gage reversals associated with gradual buckling.

The effect of normal pressure on the critical compressive stress is shown in figure 6. The specimens with a rib spacing of 6 inches and an R/t of 700 and 1000 show a decrease in critical compressive stress with increasing normal pressure. With these specimens no inward buckling occurred but, since the introduction of pressure caused the sheet to bulge out under the initial compression load, the load at which the strain-gage readings reversed was lowered. In specimens in which snap diaphragm buckling occurred, there was a pronounced increase in critical compressive stress with increasing normal pressure. The results of the tests of the specimens with an infinite radius do not show any decisive trend and in most cases no buckling load could be obtained.

The effect of normal pressure on the critical shear stress is shown in figure 7. In all cases an increase in normal pressure caused an increase in critical shear stress. This result was independent of whether buckling occurred slowly or with a snap.

The data of figures 6 and 7 show that, in general, the greater the R/t ratio, the greater the percentage increase in critical compressive and shear stress with increasing normal pressure.

Experimental rotation is compared with theoretical rotation for the torsion specimens at various R/t ratios, rib spacings, and normal pressures in figure 8. Theoretical rotation was obtained from the formula

$$\theta = \frac{T}{GJ}$$

where

θ rotation, radians per inch of length

T measured torque, inch-pounds

G shear modulus (here taken as 4.0×10^6 psi)

J torsional-stiffness constant, inches^4

The data of figure 8 show that the torsional stiffness of the specimens before buckling is slightly increased by increasing normal pressure. These slight increases in torsional stiffness might be explained, at least in part, by the fact that bulging of the sheet resulting from internal pressure produced an increase in the enclosed area of the specimen. This effect is more pronounced in the specimens with a 24-inch rib spacing than in the specimens with a 6-inch rib spacing, as evidenced by the test results in figure 8.

CONCLUSIONS

The results of tests of 40 specimens to determine the effect of normal pressure on the critical compressive and shear stress of curved sheet indicated the following conclusions:

1. Normal pressure appreciably raised the critical compressive stress for curved sheet when inward snap diaphragm buckling occurred.

2. Normal pressure lowered the critical compressive stress for curved sheet when outward bulging occurred.

3. Normal pressure raised the critical shear stress for curved and flat sheet regardless of whether buckles formed slowly or with a snap.

4. The greater the ratio of radius of curvature to thickness of the sheet, the greater the percentage increase in critical compressive and shear stress with increasing normal pressure.

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REFERENCES

1. Rafel, Norman: Effect of Normal Pressure on the Critical Compressive Stress of Curved Sheet. NACA RB, Nov. 1942.

2. Rafel, Norman: Effect of Normal Pressure on the Critical Shear Stress of Curved Sheet. NACA RB, Jan. 1943.

3. Timoshenko, S.: Theory of Plates and Shells. McGraw-Hill Book Co., Inc., 1940, pp. 347-350.

TABLE I

NOMINAL DIMENSIONS OF TEST SPECIMENS

[Symbols are defined in fig. 1.
All dimensions are given in inches.]

Specimen	d	a	L	R	R/t
1, 2	3	6	25.5	25.6	400
3, 4	5	12	47.5	25.6	400
5, 6	5	18	65.5	25.6	400
7, 8	5	24	83.5	25.6	400
9, 10	3	6	25.5	44.8	700
11, 12	5	12	47.5	44.8	700
13, 14	5	18	65.5	44.8	700
15, 16	5	24	83.5	44.8	700
17, 18	3	6	25.5	64.0	1000
19, 20	5	12	47.5	64.0	1000
21, 22	5	18	65.5	64.0	1000
23, 24	5	24	83.5	64.0	1000
25, 26	3	6	25.5	76.9	1200
27, 28	5	12	47.5	76.9	1200
29, 30	5	18	65.5	76.9	1200
31, 32	5	24	83.5	76.9	1200
33, 34	3	6	25.5	∞	∞
35, 36	5	12	47.5	∞	∞
37, 38	5	18	65.5	∞	∞
39, 40	5	24	83.5	∞	∞

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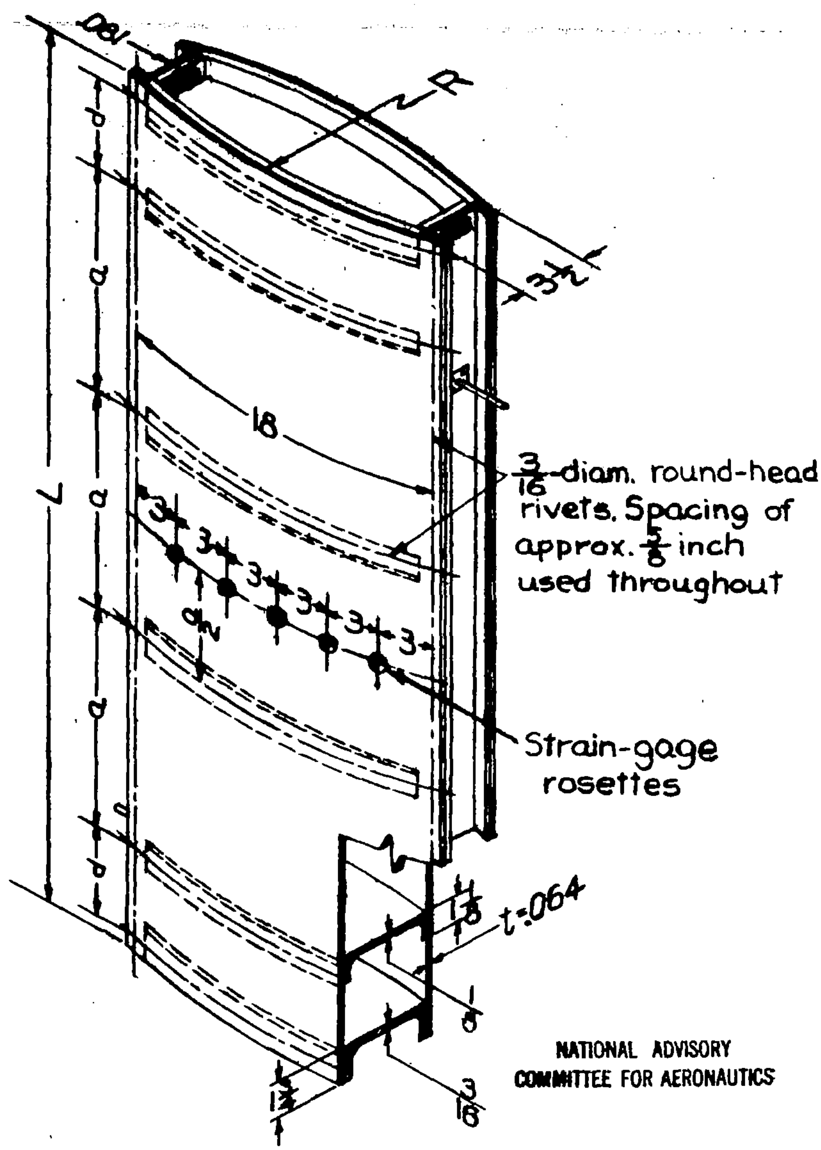
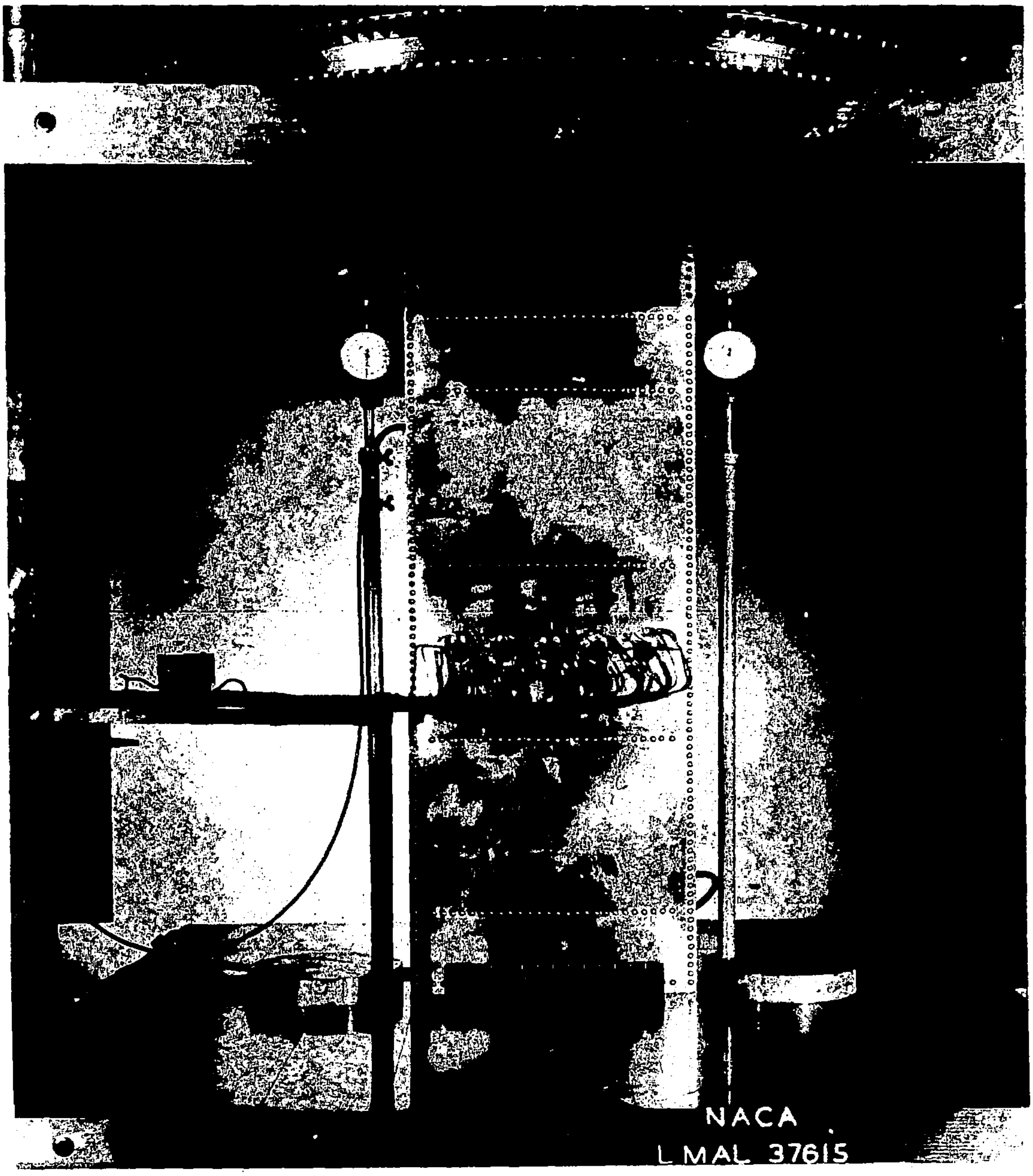


Figure 1.- Test specimen. (For dimensions not shown, see table I.)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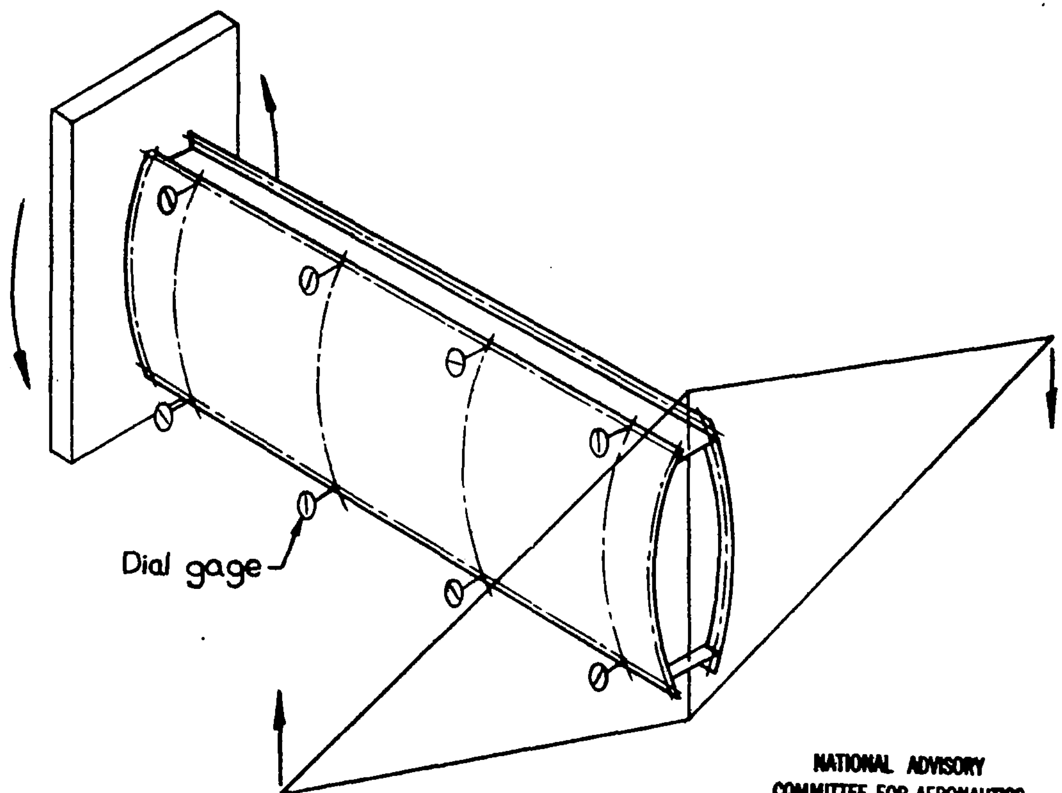

Figure 3.-Test specimen in torsion showing locations of dial gages.

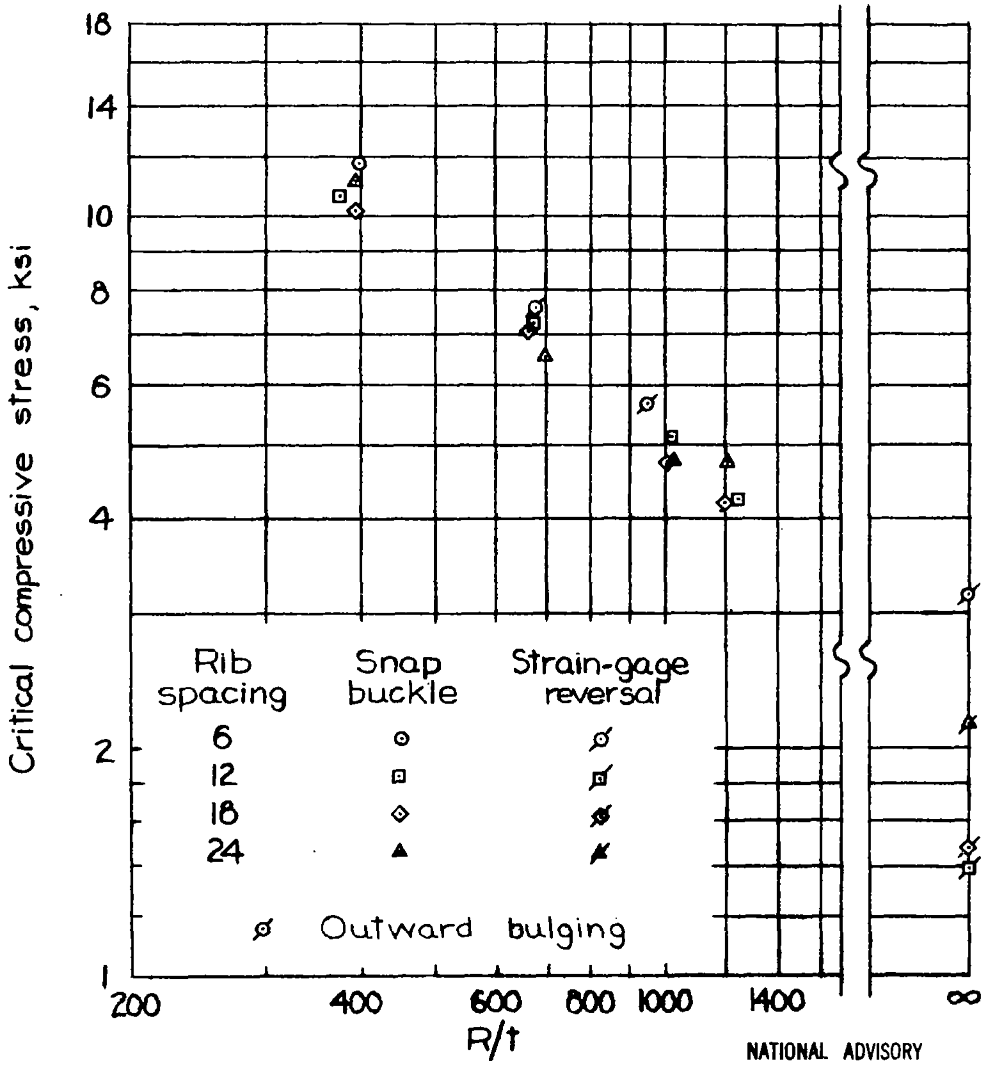

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Figure 4.- Effect of R/t and rib spacing on critical compressive stress without normal pressure.

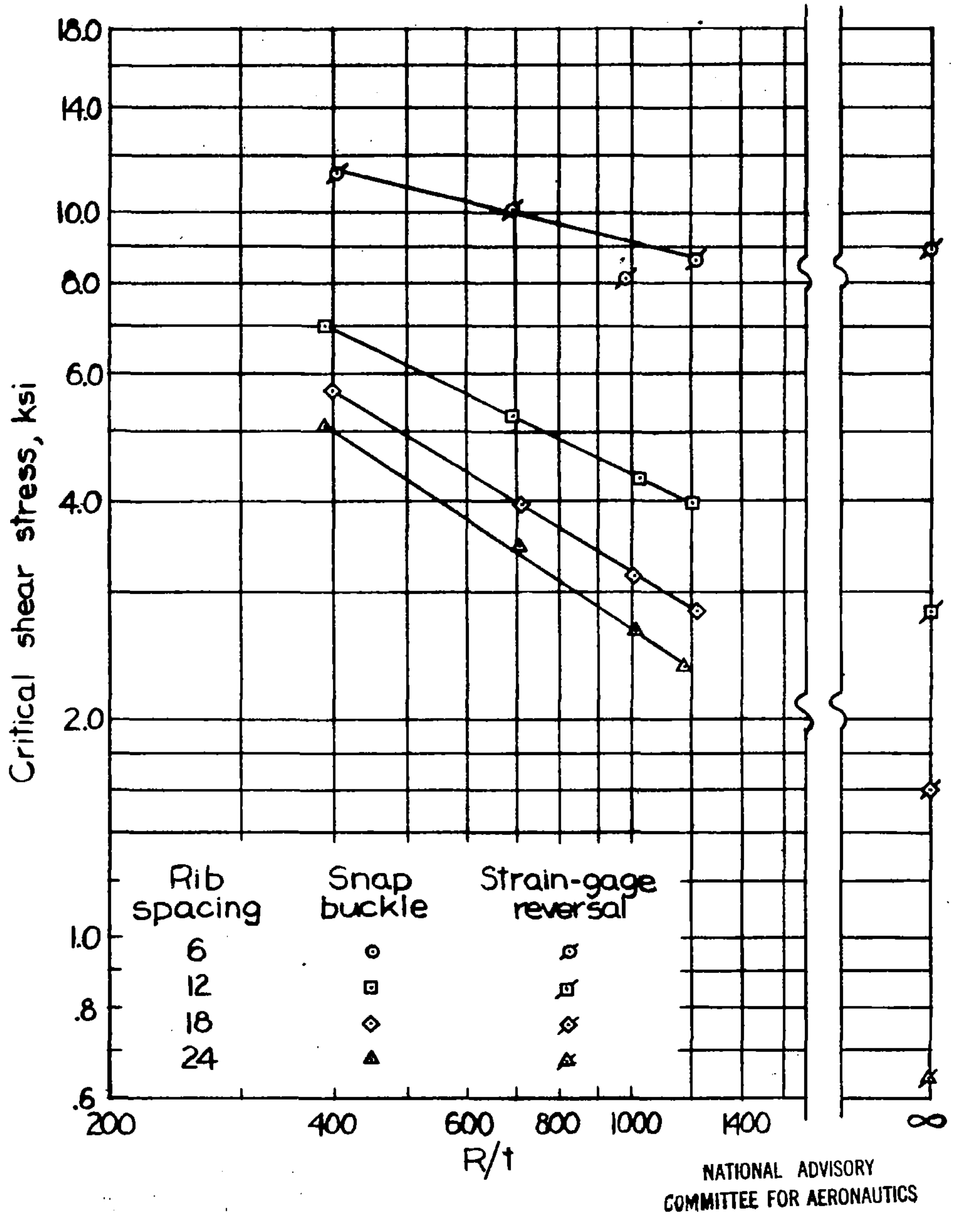

Figure 5.- Effect of R/t and rib spacing on critical shear stress without normal pressure.

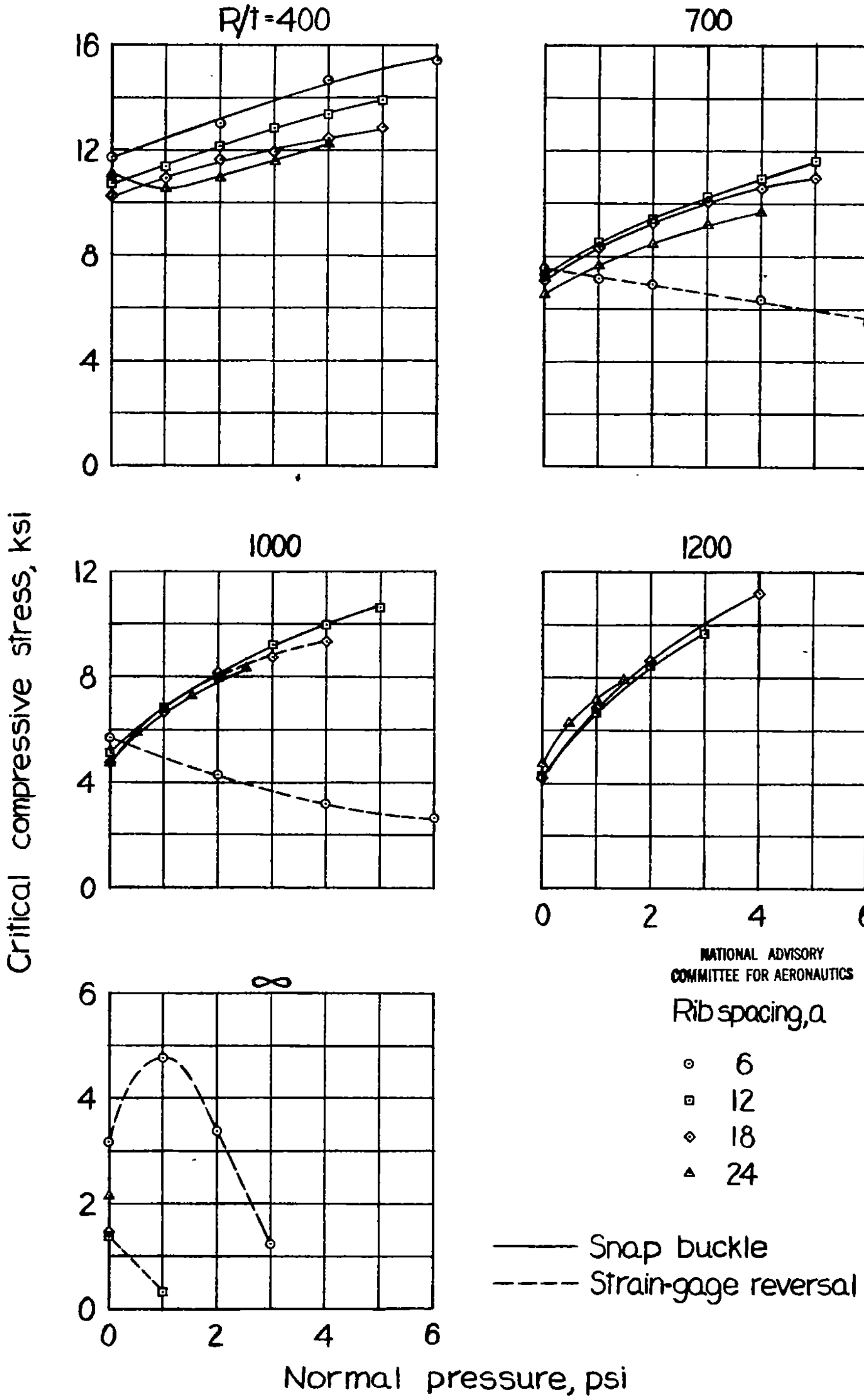

Figure 6.- Effect of normal pressure on critical compressive stress.

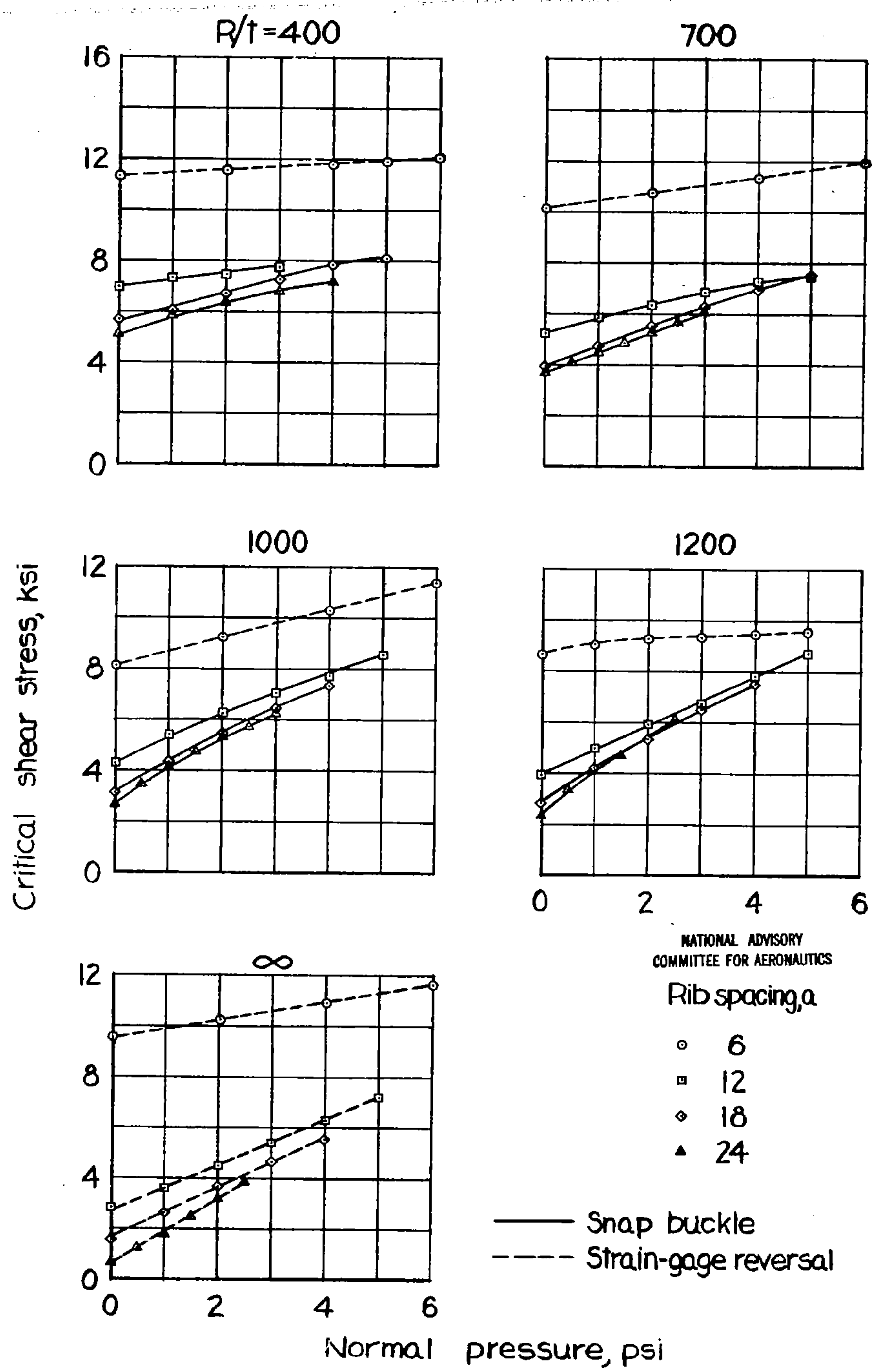

Figure 7.– Effect of normal pressure on critical shear stress.

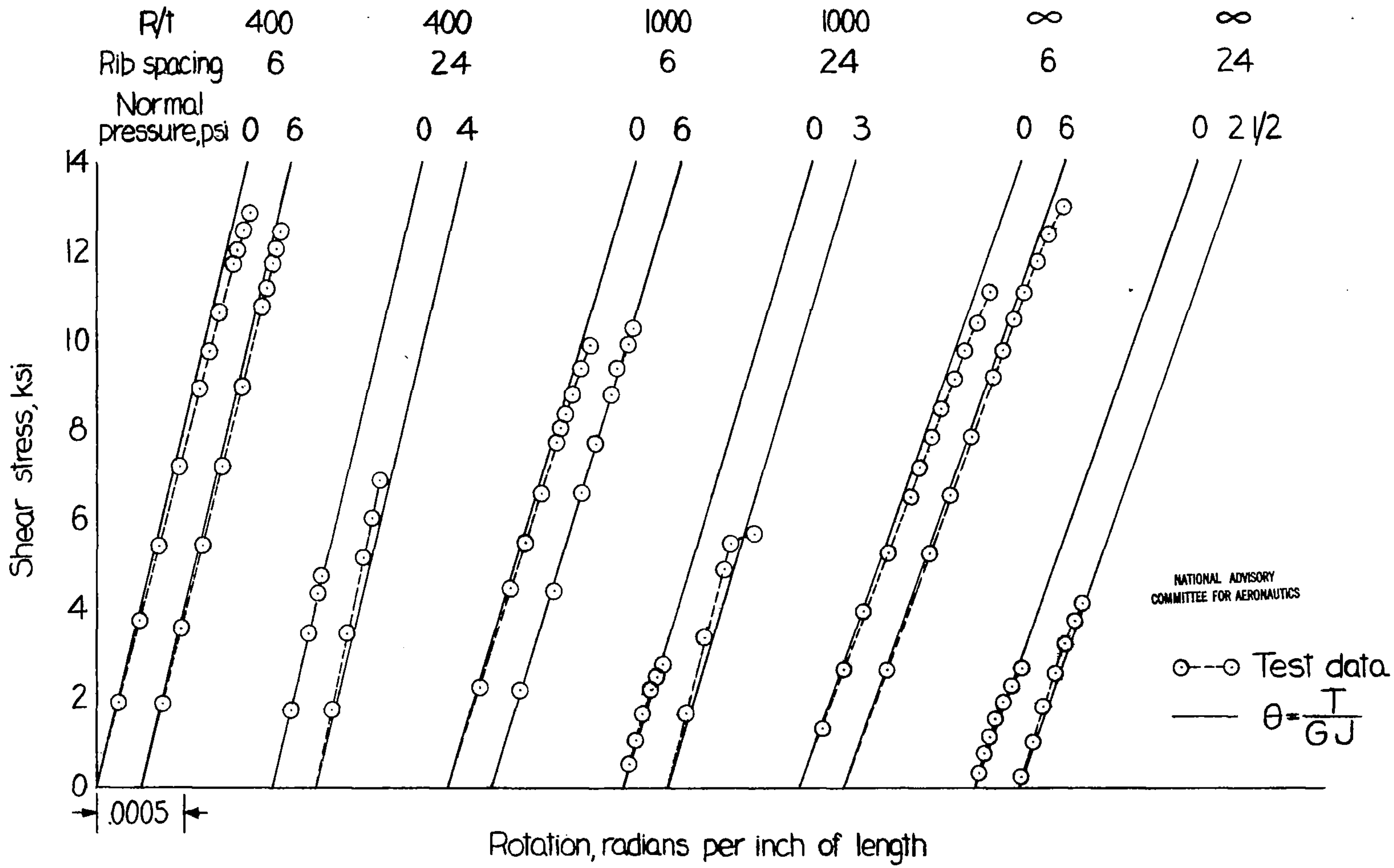

Figure 8.- Shear stress-rotation curves for torsion specimens with various R/t ratios, rib spacings, and normal pressures.